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ORIGINAL PAPER

Effects of wheeled cable skidder on rut formation in skid trail - a case study in Hyrcanian forest

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Abstract: The impact of skidding operations on forest soils can be divided into three major categories: soil profile disturbance, soil compaction, and soil puddling and rutting. The present study was designed as a factorial experiment in the Kheyrud Forest with a Timberjack cable skidder to evaluate the influences of number of machine passes and soil moisture of skid trails on rutting over a fine-grained soil, and to quantify these effects. The effects of soil moisture of 20%–30%, 30%–40% and 40%–50% and different levels of compaction were studied. Compaction treatments were applied using different numbers of skidding passes (1, 5, 10, 15, 20, 25, 30 times). Result shows that an increase in the number of machine passes could increase rut depth, but the majority of rutting was occurred after the initial few machine passes. Also rut depth at soil moisture of 40%–50% was higher than rut depths at soil moisture of 30%–40% and 20%–30%. The average rut depth in soil with 20%–30%, 30%–40% and 40%–50% moisture was 17, 22 and 35 cm, respectively. Rut depths were increased significantly with soil moisture and number of machine passes. It is suggested that skidding operations should be planned when soil conditions are dry in order to minimize rutting., but if skidding must be done under wet conditions, the operations should be stopped when machine traffic could create deep ruts.

Keywords: wheeled cable skidder; rut formation; disturbance; soil moisture; number of passes

Introduction

Hyrcanian (Caspian) forest in northern Iran has a richness of biological diversity of endemic and endangered species. Rubber-tired skidders are used on the more gentle slopes and on designated skid roads in steeper terrain. Crawler tractors (bulldozers) are used on steeper topography to skid directly to the landing (Sobhani and Stuart 1991). The use of wheeled and tracked skidders is widely seen and well accepted practice in Hyrcanian forest. It is also the one that tends to cause the greatest environmental problems. Forest soils, in general, are susceptible to compaction as they are loose with high organic-matter, and are generally low in bulk density, high in porosity, and low in strength (Froehlich and McNabb 1984; Froehlich et al. 1985; Kolkaa and Smidt 2004; Horn et al. 2007). The impact of skidding operations on forest soils can be divided into three major categories: soil profile disturbance, soil compaction, and soil puddling and rutting (Cullen 1991; Grace et al. 2006). When a mechanical load is applied on the soil, soil particles are rearranged closer together resulting in increasing bulk density (mass per unit volume), (Dickerson 1976; Greacen and Sands 1980; Grace et al. 2006). One of the major impacts of harvesting operations is soil profile disturbance (Grace et al. 2006). A serious consequence of low permeability of severely compacted soil is runoff of water, which reduces soil water recharge and often leads to soil erosion (Adams and Froehlich 1984; Kozlowski 1999; Gomez et al. 2002). During timber harvesting, the degree of soil compaction depends on various factors including site and soil characteristics (Ampoorter et al. 2007), soil moisture (Johnson et al. 2007), the number of machine passes (Eliasson and Wasterlund 2007; Wang et al. 2007), and type of machine (Susnjar et al. 2006; Wang et al. 2007).

A couple of studies showed that one of the critical factors, which affects the degree of soil compaction and rutting, was the number of machine passes over a specific point (Gayoso and Iroume 1991; Ampoorter et al. 2007; Eliasson and Wasterlund 2007). Generally, displacement of the organic layer and mineral soil occurs by scalping, log rolling, gouging, rutting and puddling. Rutted and puddled soils occur during more moist conditions when equipment pressure causes the breakdown of the soil structure (Greacen and Sands 1980; McNabb et al. 2001; Nugent et al. 2003). Eliasson (2005) stated that rut depths were not significantly affected by tire pressures but increased significantly

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with the number of machine passes. Eliasson and Wasterlund (2007) showed that rut depths increased with number of machine passes but were not influenced by slash depth. During wet conditions, some wheel-ruttings could be expected on all soils (Turcotte et al. 1991). Rollerson (1990) found that increasing levels of skidder traffic led to increasing depths of rutting. Rutting depths tended to be deeper for moist than for dry soil conditions, and the effect often becomes more noticeable with increasing traffic.

In Hyrcanian forest, a few studies have been carried out on the effects of forest operations on soil compaction and bulk density. Evaluations of the soil impacts among soil moisture and number of machine passes seem necessary in this forest for pre-planning and layout of skid trials and to promote forest management to environmentally sound forest harvesting. The specific objectives of the present study were to: assess the extent of the rut formation and its relation with soil moisture, and to measure and establish the threshold levels for the machine traffic with respect to surface rutting for 3 levels of soil moisture.

Materials and methods

Study sites

The research was carried out in mountainous conditions of compartment number 220, which is located in Namkhaneh District within Kheyrud Educational and Research Forest. The altitude ranging is 1 000–1 135 m above sea level and the forest lies on a southwestern aspect. Average rainfall ranges from 1420 to 1530 $mm \cdot a^{-1}$, with the heaviest precipitation in the summer and fall. The average daily temperatures are moderate, ranging from a few degrees below 0°C in December, January, and February to +25°C during the summer. This area was dominated by natural forests containing native mixed deciduous tree species such as *Fagus orientalis* Lipsky, *Carpinus betulus* L., *Acer velutinum* Boiss. and *Alnus subcordata*. The mixed un-even aged high forest is managed with single and group selective cutting regime. The soil of study site is classified as a brown forest soil (*Alfisols*) and well-drained. The texture of the soil is ranging from silt loam to loamy. The soil is acidic and leached soil, with a $A_1A_2B_1B_tC$ profile. Other soil characteristics of the study site are: 20%–65% water content; 11% organic matter content; 5.1 pH (H_2O), 1.05-m average profile depth, and 1.6-m maximum depth. The operations of downhill and uphill skidding to the landing were planned without any excavation and the skidding operations have done on natural ground. The skid trail slope ranges from 0 to 35%.

Data collection

Felling of marked tree was carried out in March and skidding operation was done in August 2008. Fig. 1 depicts the 4-WD Timberjack 450c wheeled cable skidder used in the study. This machine is normally an articulated, four-wheel-drive vehicle weighing 10.3 ton (55% on the front and 45% on the rear axle) with engine power of 177 horse power and engine model of 6BTA5.9. It is equipped with a blade for light pushing of obstacles and stacking of logs. The skidder was fitted with size of 24.5–32 tyres which was inflated to 220 kPa on both front and rear axles, and had a ground clearance approximately 0.6 m with overall width of 3.1 m. Timbers were carried out by the winch installed in the rear part of the skidder from the stump to depot. In study areas, the average logged volumes in each pass were 3.5 m^3 (1-3 logs).

Fig. 1 Timberjack skidder extracting a log from the forest in the study area

Nine sampling transects were selected at different slope gradients along the designated skid trail for bulk density measurements (Fig. 2). Organic horizons were removed from the soil surface prior to density measurements, so that depth readings were referenced to the mineral soil surface. Before skidding operation, four slope gradients in the skid trail with 3 replications were established in disturbed areas at soil profile depth of 0-10 cm, and the different levels of compaction were applied by varying the levels of machine traffic: 0 (undisturbed), 1, 5, 8, 10, 15, 20, 25, and 30 times of machine passes. A pass implies a drive back and forth the selected trail.

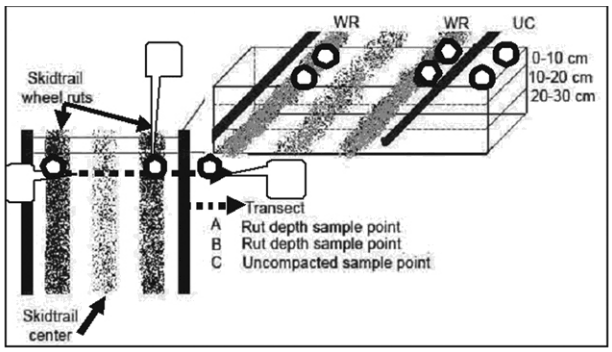

Fig. 2 Sketch of study layout and soil sampling for bulk density and rut depth

In order to evaluate the soil moisture effects on rut formation, three soil moisture categories at 20%–30%, 30%–40%, and 40%–50% water content in three replications were installed in skid trails before skidding operation. Rut depths were measured as the distance (20-cm intervals) among the underside of an alu-

minums rod (4-m long) lies across the rut (transect line in Fig. 3) and undisturbed ground surface. The measurement was made centrally in the skid trail at numbers of 1, 5, 10, 15, 20, and 30 machine passes. Two wooden posts were used to tie a 4-m aluminums horizontal rod across the transect line for measurement of perpendicular rut depth using a meter rule.

Fig. 3 Measurements of rut depth in study area

Statistical analysis

The experimental design was a factorial arrangement of treatments conducted in a completely randomized design. Data were evaluated for normality before running the analyses. We also applied general linear modeling (GLM) to relate rut depth to machine passes, and soil moisture in relation to the skid trails. Post-hoc comparison of means and Duncan's multiple design was used to grouping with a 95% confidence level. Analysis of variance of the test data was conducted in SPSS (release 11.0.0). Treatment effects were considered significant ($p<0.05$).

Results

Rut depth (Table 1 and Fig. 4, 5) was increased significantly by the soil moisture (p = 0.00) and number of machine passes (p = 0.00), but not affected significantly by the interactions between number of machine passes and soil moisture (p = 0.45).

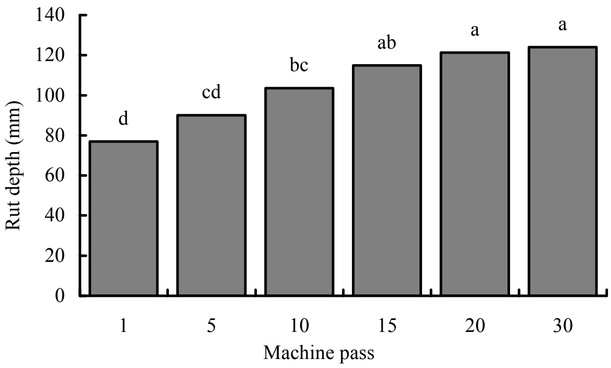

Fig. 4 Average of the rut depth in skid trail after different numbers of machine passes. Mean values followed by the same letter are not statistically different by Duncan's test.

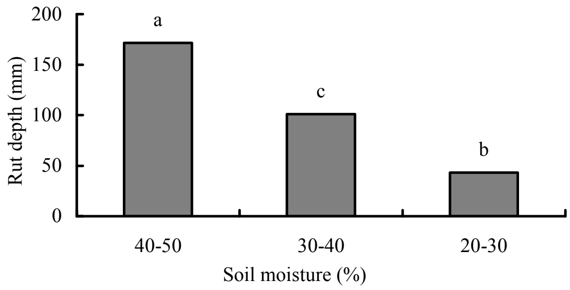

Fig. 5 Average the rut depths in skid trail with different soil moistures. Mean values followed by the same letter are not statistically different by Duncan's test.

Table 1. Analysis of variance (ANOVA) for the effect of soil moisture (SM) and number of machine passes (NP) on rut depth in skid trials

Source	Sum of square	*df*	Mean of Square	*F*	*p*-value
Number of pass	148732	2	74336	354.22	0.00
Soil moisture	15645.5	5	3129.1	14.9	0.00
Number of pass × Soil moisture	2136	10	213.6	1.02	0.45

To compare the rut depth in three soil moisture groups per machine pass, we used one-way analysis of variance (ANOVA) and Duncan's test to see if there were significant differences ($p \le 0.05$) between the rut depths. In general, rut depth increased significantly with soil moisture (Fig. 6). Average rut depths were 43, 101, and 172 mm for 20%–30%, 30%–40%, and 40%–50% soil moisture content, respectively, and rut depth was significantly separated from each other. After 30 times of machine passes rut depth for the 40%–50% soil moisture has the highest value (Fig. 7).

On the other hand, soil moisture affects the degree of soil compaction as it can lubricate, as well as provide cohesion to soil particles. Up to and including the optimum moisture content, water can lubricate soil particles and allow their reorientation with respect to each other, then puddling and rutting occurred. Average rutting depths under lower moisture conditions (20%–30%) were generally less than 12 cm even with heavy traffic. Average rutting depths under 40%–50% moist condition ranged between depths of 7 and 45 mm. Average rut depth was significantly affected by the number of machine passes (Fig. 6). The wheeled machine left visible bulging alongside the ruts. The trail with 40%–50% soil moisture showed the highest increase of rut depth at wheel tracks after the first 15 numbers of machine passes (Duncan's). For trail of 40%–50% soil moisture content, average rut depths were 135 mm after 1 number of machine pass, 153 mm after 5 times of machine passes, 168 mm after 10 numbers of machine passes, and 189 mm after 15 numbers of machine passes. Beyond 15 cycles, very little increase in rut depth was noted. In trail with 30%–40% soil moisture, the highest level of rut depth was occurred at 20 numbers of machine passes (Duncan's) and additional numbers of machine passes did not

significantly increase rut depth. Under this moisture condition, average rut depths were 72 mm after 1 number of machine pass, 84 mm after 5 numbers of machine passes, 95 mm after 10 numbers of machine passes, 104 mm after 15 numbers of machine passes, and 125 mm after 20 numbers of machine passes. Average rutting depths under dry condition (20%–30% soil moisture content) ranged between 24 and 52 mm. Rut depth after 15 numbers of machine passes with the wheeled skidder was twice to the depth reached after 2 numbers of machine passes. In dry soil condition minimum rut depth was occurred and after additional number of machine passes, surface soil structure was destroyed and soil approached a powdery state, then dusty particle was formed.

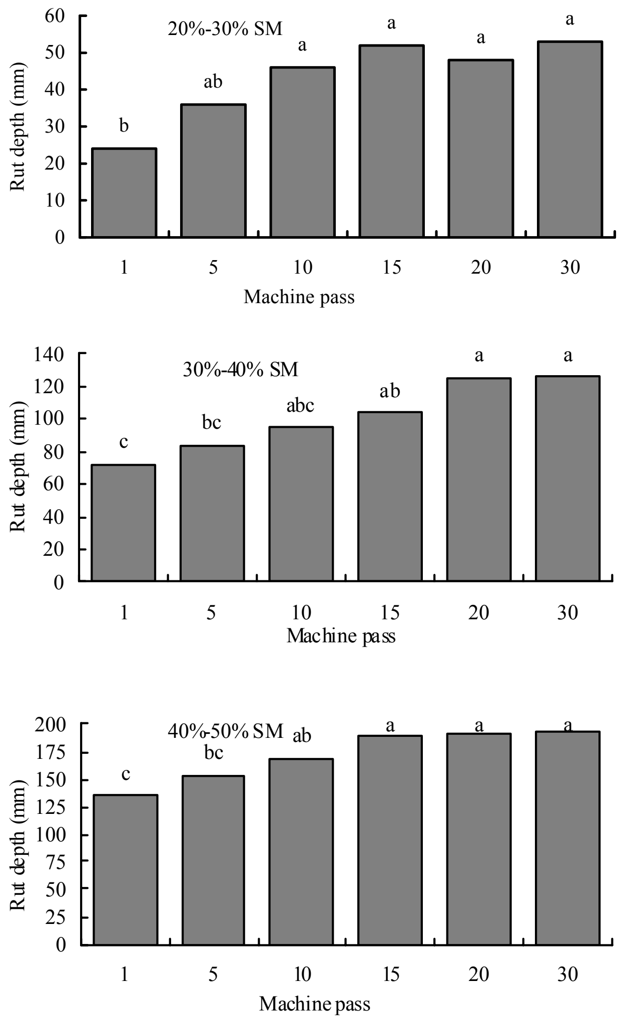

Fig. 6 Mean rut depth of three soil moisture contents in skid trail after different numbers of machine passes. Mean values followed by the same letter are not statistically different by Duncan's test.

Discussion

In general, rut depth increased significantly with soil moisture. Average rut depths were 172, 101, and 43 mm for 20%–30%, 30%–40%, and 40%–50% soil moisture content, respectively, and rut depth was significantly separated from each other. Several authors reported that in wet soils that have very low bearing strength, rutting is produced by the largely lateral soil displacement by wheels or tracks (Greacen and Sands 1980; Rollerson 1990; Turcotte et al. 1991; McNabb et al. 2001; Eliasson and Wasterlund 2007). After 30 numbers of machine passes, rut depth for the 40%–50% soil moisture has the highest value. There was a clear difference in the depth of the ruts formed by the three soil moisture contents: the dry soil caused shallow ruts and left the organic layer and root mat intact, whereas the wetter soil mixed the organic layer into the mineral soil. Deep ruts can conduct water during precipitation events and thus increase the risk of soil erosion. Rollerson (1990) reported that rutting depths tended to be deeper for moist than for dry soil conditions, and the effect often becomes more noticeable with increasing traffics. We resulted that the average rutting depth under lower moisture conditions (20%–30%) were generally less than 6 cm even with heavy traffic. Average rutting depths under moist condition ranged between depths of 7 and 19 cm. Our result was accordance to the Rollerson (1990) study. Generally, increasing levels of skidder traffic led to increasing depths of rutting. This is consistent with findings in previous studies (Nugent et al. 2003; Eliasson 2005; Susnjar et al. 2006).

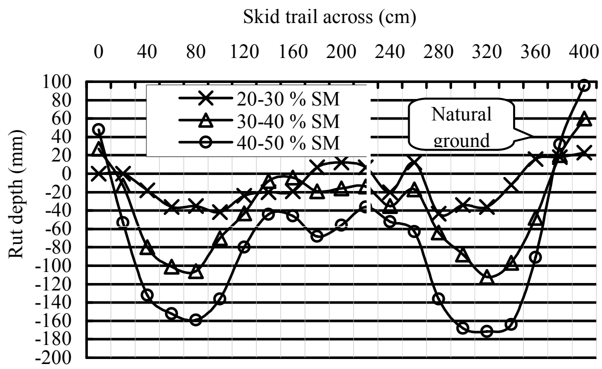

Fig. 7 Relation between rut depth and soil moisture content, 'Distance' refers to measurements along the transect lines (from Fig. 3).

Rut depth after 15 numbers of machine passes with the wheeled skidder was twice to the depth reached after 2 numbers of machine passes. In dry soil condition, minimum rut depth was occurred and after additional numbers of machine passes, surface soil structure was destroyed and soil approached a powdery state, then dusty particle was formed. Eliasson and Wasterlund (2007) showed that rut depths increased with number of machine passes. Also, Eliasson (2005) stated that rut depths were increased significantly with the number of machine passages. Surface water may accumulate in depressions and ruts following logging, thereby giving localized pockets of soil having poor aeration (Greacen and Sands 1980). Deep ruts (as the soil BD increases and pore space decreases accordingly) led to decline the rate of infiltration of rain. However, Kozlowski (1999) showed that slow infiltration lead to soil water deficit, surface runoff, sheet

erosion and gully formation.

Conclusions

Soil moisture has significant effects on soil compaction. One strategy to limit soil disturbances is to avoid traffic whenever the water content approaches the limit of liquidity (above 40% soil moisture content), or even exceeds it. Skidding operations should be planned when soil conditions are dry so as to minimize rutting, but if skidding must be done under wet conditions, the operations should be stopped when machine traffic was created deep ruts. Another approach is to limit traffic on skid trails. Traffic trails should be developed for forest sites in order to concentrate most forest operations to compacted trails. In Hyrcanian forest which was managed by uneven-aged method, all trees aren’t felled in harvesting period, thus the strengthening effects and damages of the roots persist and growth losses due to root damage will occur. Therefore, more attention should be given to degradation in fine-textured and acid forest soils, with low levels of biological activity.

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